Chapter -1

INTRODUCTION

Oceans have always influenced the life and history of man. From the time immemorial, man has been using oceans in several ways. According to our mythology, the *suras (Gods)* and *asuras (Demons)* churned the ocean (*samudra manthan*) and extracted *amritam*, the elixir of life. This appears to be true now as we get many valuable items like minerals, food and energy resources from the oceans. Oceans are a huge storehouse of resources like minerals (metals, oil, natural gas, chemicals etc.), food (fish, prawns, lobsters etc.) and energy (waves, water currents, tides etc.). We have been using oceans for transporting goods (through ships and oil tankers) and for recreation purposes (beaches, water sports etc.). We have also been using oceans to dump all municipal waste, industrial effluents, pesticides used in agriculture etc. resulting from activities of the ever-growing population.

In addition, oceans control weather and climate and thus considerably influence the environment. Even the quality of air that we breathe depends greatly on the interaction between the oceans and the atmosphere.

Oceanography is a relatively young branch of science. The Challenger Expedition in 1872-1876 began the exploration of the deep sea but it was during World War II that the significance of this knowledge became of national importance. During the first few decades after World War II there was a tremendous efflorescence in our understanding of fundamental processes in the sea; in ocean circulation, plate tectonics, and the biochemical basis for the productivity of marine life. Oceanography expanded rapidly and then, of necessity, grew more slowly until it is now a mature discipline. So this is a very suitable point to look back at our achievements.

Hydrography

The fashion at that time was to map the measured scalar fields of temperature and salinity and to infer the current velocities by a joint application of the hydrostatic and geostrophic equations. Since the scalar fields were relatively smooth and steady, the inferred currents were relatively smooth and steady.

There are two shortcomings to the hydrographic method. First, smooth scalar distributions do not necessarily call for smooth, steady current systems, the scalar fields being space and time integrals of the motion field. One has found smooth scalar fields in the presence of extremely complex float trajectories. The downed flyers would have found the current charts useful only if they had been willing to integrate their drifting experience over a year or two. The second shortcoming is that the hydrographic method gives only *relative* currents, and much effort has been expended to find the so-called depth of no motion.

Abyssal Circulation

The basic elements of the deep (thermohaline) ocean circulation were known in Sverdrup's time. (He mapped global volume fluxes in units of million cubic meters per second, now known as *sverdrups*.) At the time it was believed that deep water known as Montgomery's "common water" was formed in a few concentrated areas south of Greenland and along the Antarctic Shelf by top-to-bottom convection.

Ekman Spiral

All students of oceanography learn about the Ekman spiral, an elegant early-century mathematical solution to the wind-driven current profile. In more general terms, "Ekman

dynamics" has been observationally confirmed by Davis in the Mixed Layer Experiment (MILE), and by Rudnick in an acoustic Doppler current profiler (ADCP) transect across the Atlantic.

Understanding Variability

Fifty years ago physical oceanographers were deploying around the ocean in a few vessels taking Nansen casts and bathythermographs (BTs). The underlying theology was that of a *steady* ocean circulation: differences between stations were attributed to the difference in station *position*, not the difference in station *time*. We now know that more than 99 percent of the kinetic energy of ocean currents is associated with variable currents, the so-called meso-scale of roughly 100 km and 100 days. Incredible as it may seem, for one hundred years this dominant component of ocean circulation had slipped through the coarse grid of traditional sampling. Our concept of ocean currents has changed from something like 10 ± 1cm/s to 1 ± 10 cm/s. This first century of oceanography, since the days of the *Challenger* expedition in the 1870s, came to an abrupt end in the 1970s.

The Mesoscale Revolution

By 1950, the oceanographic community had become aware of the meandering of the Gulf Stream. Fritz Fuglister dramatically demonstrated the shedding of a cold-core eddy in the Gulf Stream region. At first it was thought that transients are confined to the regions of the western boundary currents.

But the acoustic tracking of neutrally buoyant floats by Swallow (who credits Stommel for suggesting this idea) soon demonstrated that variability in space and time was the rule, not the exception (though more intense near the boundary currents). There was an urgent need for a systematic exploration of the ocean variability. The development of deep-ocean mooring technology provided such an opportunity, and the Mid-Ocean Dynamics Experiment (MODE) starting in 1973 under the leadership of Stommel and Robinson defined the parameters of variability.

Major world (U.S) programs:

How some of the major physical oceanography programs developed subsequent to the International Decade of Ocean Exploration (IDOE) through the rise of the global change programs is interesting to be noted. The emphasis here is primarily on the major physical oceanography programs, WOCE (the World Ocean Circulation Experiment), which was primarily an oceanographic program, and TOGA (the Tropical Ocean and Global Atmosphere program), which was a truly interdisciplinary program involving both the atmospheric and the oceanic communities. The next program called CLImate VARiability, (CLIVAR) is now viewed as the next major atmosphere-ocean program, with the goal of greatly improving our ability to forecast variations in climate on very long time scales. CLIVAR field programs are expected to last at least through the next decade and perhaps provide at least scientific motivation for the long-awaited Global Ocean Observing System, perhaps even a Global Climate Observing System.

Recalling the four major components of IDOE, they are Environmental Forecasting (EF), Environmental Quality (EQ), Living Resources (LR), and Nonliving Resources, or Sea Bed Assessment (SBA). The EF program consisted largely of physical oceanography programs. The major examples are MODE (Mid-Ocean Dynamics Experiment), POLYMODE (the U.S.-Soviet follow-on to MODE), NORPAX (North Pacific Experiment), ISOS (International Southern Ocean Studies), CLIMAP (Climate Long-range Investigation, Mapping, and Prediction Study), and CUEA (Coastal Upwelling Ecosystems Analysis). The latter two showed the way to truly interdisciplinary work, with CLIMAP studying physical phenomena in the distant past using paleo- oceanographic techniques and CUEA showing the way to investigating the physical impacts on fisheries, or "living resources."

Another legacy of the IDOE was the start-up of a number of midsize programs. Some examples are the Coastal Ocean Dynamics Experiment (CODE); Tropic Heat (TH), a study of the Eastern Pacific Cold Tongue; Pacific Equatorial Ocean Dynamics Experiment (PEQUOD); the Western Equatorial Pacific Ocean Circulation Study (WEPOCS); and Transient Tracers in the Ocean (TTO), which was a follow on to the Geochemical Ocean Sections (GEOSECS) study, and a precursor to the tracer work to be done in WOCE and other survey experiments. This is another example of two disciplines coming together to study common problems. MODE, was the first comprehensive look at the mesoscale eddy field. Followed by the joint Russian-U.S. POLYMODE, it paved the way for the World Ocean Circulation Experiment. In a similar fashion, the GEOSECS program, leading into the study of Transient Tracers, also paved the way for the high precision tracer work during WOCE.
Similarly, NORPAX, expanding its range with the Hawaii to Tahiti Shuttle, largely a survey using expendable bathythermographs with frequent crossings of the equator, was one of many midsize programs that paved the way for TOGA. Others include Tropic Heat, PEQUOD, WEPOCS, the National Oceanic and Atmospheric Administration's EPOCS (Eastern Pacific Ocean Climate Study), and others.

The Future of Physical Oceanography:

The National Science Foundation (NSF) asked the U.S. physical oceanographic community in 1997 to evaluate the current status of research in physical oceanography and to identify future opportunities and infrastructure needs. The Scientific community was asked to consider advances in physical oceanography over the last twenty years. The following items were widely hailed as significant recent achievements: a revolutionary understanding of the coupling of the tropical ocean and atmosphere and the development of predictive El Niño models; estimation of the global distribution of mesoscale variability in the world ocean and theories and models of this geostrophic turbulence; completion of the World Ocean Circulation Experiment and improved estimates of the pathways and timescales of the circulation; and quantitative measurements of the strength of small-scale ocean mixing and the dependence of this mixing on the strength of the internal wave field and other environmental conditions.

The community was also asked to look into the future and forecast advances for the next twenty years. Great excitement was expressed at the prospect of new tools that might solve the problem of observing the global ocean. Already the TOPEX/POSEIDON satellite mission has measured the topography of the sea surface to 3 cm accuracy at 7 km spacing for 5 years. Future developments in satellite oceanography promise global measurements of sea surface salinity and precipitation. These measurements are crucial if we are to understand the climate system and the hydrologic cycle. Yet sea-truth is essential and *in situ* water-column observations made by an unprecedented class of autonomous instruments are anticipated. Integrating measurements, such as tomography, and the installation of cheap and easy-to-use probes on ships-of-opportunity, hold great promise.

Even with present technology, a description and an understanding of the spatial distribution of turbulent processes in the global ocean is achievable in the next decade. Our present conception of ocean dynamics is largely ignorant of processes with relatively short horizontal length scales (say 100 m to 50 km). Yet biological variability is concentrated on these short scales. It is the dynamics on these same scales that is parameterized by eddy-resolving circulation models. Further, in the coastal zones, cross-shelf exchanges are likely mediated by instabilities and topographic influences whose horizontal scales are much less than those of the well-studied alongshore flow. Exploring these largely unvisited scales is a new frontier for physical oceanography.

Future Directions:

The economic benefits of understanding the role of the ocean in the climate system are enormous. And accumulating evidence of man-made climate change has brought these issues to the attention of the public. These concerns coincide with recent successes in long-term weather forecasting associated with El Niño, and with advances that enable detailed measurement of climate variables. (For instance, in the last ten years, the errors in surface heat fluxes obtained from moorings have been reduced by a factor of forty so that the present uncertainty is 5 Watts per square meter.) These factors imply that climate studies will be a significant path for future research in oceanography.

The development of long-term forecasting skills raises challenging scientific problems. These include: understanding and quantifying turbulent mixing, convection, and water- mass formation and destruction; the thermohaline circulation and its coupling to the wind-driven circulation; the generation, maintenance, and destruction of climatic anomalies; climatic oscillations and the extratropical coupling of the ocean and atmosphere on seasonal, decadal, and interdecadal timescales; and the physics of exchange processes between the ocean and the atmosphere. All these problems are of fundamental scientific and practical importance.

The problem of global climate prediction is the most difficult that our field has encountered. Unlike equatorial oceanography and El Niño, there is not going to be a theory based on linear waveguide dynamics that decisively identifies timescales and cohesively binds oceanography and meteorology. Could meteorologists have developed daily weather prediction?
Models if these scientists saw only three or four independent realizations of the system in a lifetime? The only way around this statistical problem is to expand our data base and frame hypotheses about past climate change and ocean circulation using paleo-oceanographic studies. An important challenge is to test the dynamical consistency of these hypotheses.

At another emerging theme, which is strongly related to climate, is the ocean's role in the hydrologic cycle. New satellite technologies promise to measure sea surface salinity and precipitation. These, coupled with improvements in the computation of evaporation via indirect methods, will improve our picture of the freshwater flux in the oceans. The freshwater sphere is an encompassing topic that spans oceanography, the atmospheric sciences, polar ice dynamics, and hydrology. Our knowledge of the oceanic freshwater source sink distribution is far poorer than our knowledge of the source-sink distribution of heat. Yet salinity and temperature contend in their joint effect on the density of seawater and in their influence on the ocean circulation, and the climate system. Knowledge of freshwater input from continents, precipitation, and sea-ice is poor. Observational techniques addressing these issues (for example, the use of oxygen isotopes, and tritium/helium to diagnose freshwater sources) herald progress. Coupled with improved estimates of the freshwater sources at the surface, will be an increased understanding of water-mass dynamics and transformations. We can look for advancement on such fundamental issues as the causes of the temperature-salinity relationship, thermocline maintenance, and inter-hemispheric water-mass exchanges.

Future developments in satellite oceanography promise more of the same at ever-increasing accuracy, coupled with the deployment of new satellite-borne instruments. Yet sea-truth is essential and we envisage *in situ* observations that will be made by an unprecedented class of autonomous instruments and probes. The ability to manipulate these tools in mid-mission is developing. While we are making enormous strides in sampling the global ocean better, we still have far to go for truly adequate spatial and temporal sampling, though the era of grossly under-sampling the global ocean is dead. A national effort to support sustained high-quality global observations over decades is needed. Measurements of air-sea fluxes of heat, fresh water, and gases, of surface and sub-surface temperature, salinity, and velocity, are all necessary to meet new scientific challenges and practical needs. Looking beyond the equatorial TOGA-TAO array, long-term subsurface measurements spanning the global ocean are required.

Given the rapid increase in Lagrangian measurements by drifting and profiling floats, and the parallel increase in geochemical tracer data, an intense approach to Lagrangian analysis of advection and diffusion is warranted; our existing base of theoretical tools and concepts is not worthy of the observations that we are about to receive.

Many emerging physical oceanographic issues concern connections between large-scale and small-scale motions; for example, the relation between small-scale turbulent mixing and the large-scale meridional overturning circulation. Analogous connections and interactions between scales are arising in issues of societal concern, often centered on the increasing recognition that many issues previously regarded as regional now require a global perspective. Anthropogenic pollutants have reached the open ocean and are known to be transported far from their sources. A better understanding is needed of small-scale processes and small-scale aqueous systems (estuaries, wetlands, coral reefs) and their impacts on global issues. For example, the growth of plankton populations, which affect carbon dioxide levels and thus may be important in global warming scenarios, is de-pendent on details of circulation at fronts, sea-ice, and mixed-layer boundaries.

In most coastal regions, the strongest persistent gradients in properties (for example, salinity, temperature, nutrients or suspended materials) are found in the cross-shelf direction. This is because cross-shelf flow is often inhibited by topography and because the coastal ocean is the contact zone between terrestrial influences, such as river runoffs, and oceanic influences characterized by nonlinear physical dynamics and oligotrophic biological conditions. Progress has certainly been made on some aspects of the flows that determine cross-shelf transports, especially those related to surface and bottom boundary layer processes. A good deal of more has yet to be learned about exchanges that occur in the interior of the water column. The problem is difficult because it often appears that the processes that are relevant for the dominant alongshore flows do not apply to cross-shelf flows. For example, it is likely that instabilities and topographic influences may dominate the exchange process. The exchange itself needs to be understood if we are to address issues such as the control of biological productivity in the coastal ocean, or the removal of contaminants from the near shore zone. In addition to cross-shelf exchange processes themselves, there is the question of how the coastal ocean couples to its surroundings on both the landward and seaward sides. Estuarine processes are important for determining the quantity and quality of terrestrial materials that reach the open shelves. The oceanic setting, including eddies, filaments, and boundary currents, in turn determines how effectively coastal influences can spread offshore, or how the oceanic reservoir will affect shelf conditions. Consequently, the study of the continental shelf demands consideration of both offshore and near-shore (estuarine and surf zone) dynamics.

Our understanding of inland waters, such as estuaries, wetlands, tide flats, and lakes, will be aided by the same observational and computational technologies that promise progress on the general circulation problem. This work will afford exciting opportunities for interdisciplinary research blending physical oceanography with biology, geochemistry, and ecology. Examples are tidal flushing through the root system of a wetland, and the physical oceanography of coral reefs. Lakes can be useful analogs of the ocean, with wind and thermally driven circulations, developing coastal fronts, and topographically steered currents. Lakes are important as model ecosystems that are simpler and more accessible than ocean ecosystems. Significant progress can be foreseen in the coming decades in limnology, helped by the tools and ideas developed for the ocean.

Past achievements in quantifying small-scale turbulent mixing in the main thermocline, coupled with exciting recent measurements in the deep ocean, suggest that a description and an understanding of the spatial distribution of turbulent mixing in the global ocean is achievable in the next decade. Unraveling the possible connections between the spatial and temporal distribution of mixing, the large-scale meridional overturning circulation, and climate variability are important aspects of this research. Knowledge of the horizontal structure of the ocean on

scales between the meso -scale (roughly 50 km) and the micro scale (roughly less than 10 m) will be radically advanced and altered. The growing use of towed and autonomous vehicles, in combination with acoustic Doppler current profilers, will revolutionize our view of the ocean by exploring and mapping these almost unvisited scales throughout the global ocean. While this research is driven by interdisciplinary forces (biological processes and variability are active on these relatively small horizontal scales) it is also a new frontier for physical oceanography, and one in which even present technology enables ocean observers to obtain impressive data sets.

Large-scale numerical models of the ocean, and of the coupled ocean-atmosphere, are becoming the centerpiece of our science. This is not to say that numerical models dominate our science, but rather that results of theory and observational data are often cast into the form of numerical models. This happens either through data assimilation or through process-model explorations of theoretical ideas. Yet the fundamental difficulty of computer modeling remains: the ocean has, in its balanced circulation, energy-containing eddies of such small scale (less than 100 km) that explicit resolution of these dominant elements is marginally possible. Compounding this difficulty are the unbalanced, three-dimensional turbulent motions that are known to be important in select areas, such as the sites of open ocean convection. We now have a well-acknowledged list of subregions of general circulation models that are greatly in need of improvement. These include: deep convection; boundary currents and benthic boundary layers; the representation of the dynamics and thermohaline variability of the upper mixed layer; fluxes across the air-sea interface; diapycnal mixing; and topographic effects. Progress in all of these areas is likely as our capacity for modeling smaller scale features increases, and as physically-based parameterizations are developed.

The large scale ocean circulation has bearing on the food web of the oceans. The current concept of the food web structure in the pelagic water – column is shown in figure1.1.

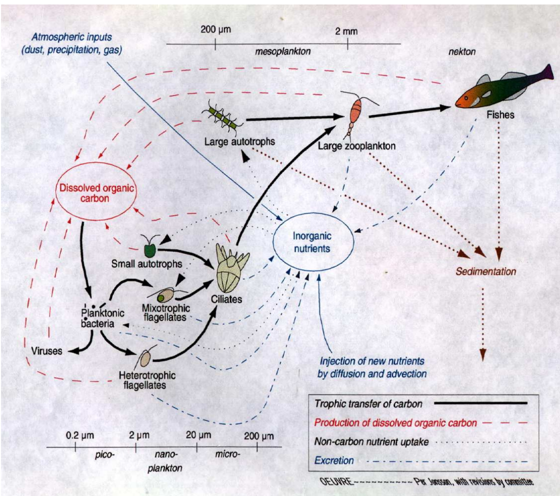


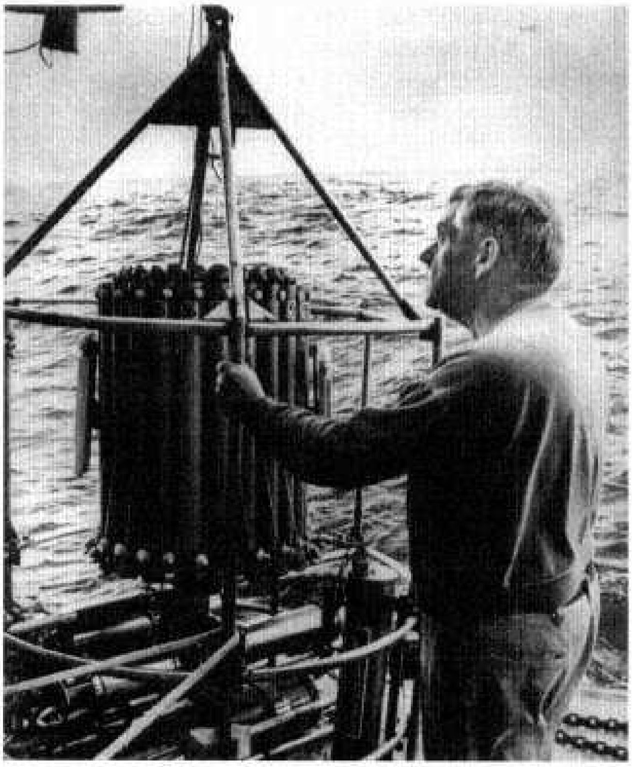
Fig.1.1. A conceptual diagram showing the current concept of the predominate food web structure in the pelagic water column. Recognition of the role of microbes has added a suite of new trophic levels to the classic “diatom-zooplankton-fish” food chain. Organisms at the lower left, whose sizes are indicated roughly by the adjacent scale bar, are responsible for the fluxes indicated by arrows.

The above views are given by Dr.John Knauss, Dr.Dick Barber and Walter Munk.



Photos.1.1. Left to right - John Knauss , Dick Barber , Walter Munk (center)and Judith Munk, wife of Walter Munk (sitting)

Now a days there are a wide and increasing use of oceans and their coastal zones. Particularly, in India, it is used for transportation, recreation, tourism, coastal industrialization, exploitation of placer deposits like rare earth minerals, salt, foreshore and offshore oil and natural gas deposits, fisheries etc. Some of them are shown below.



Henry Stommel

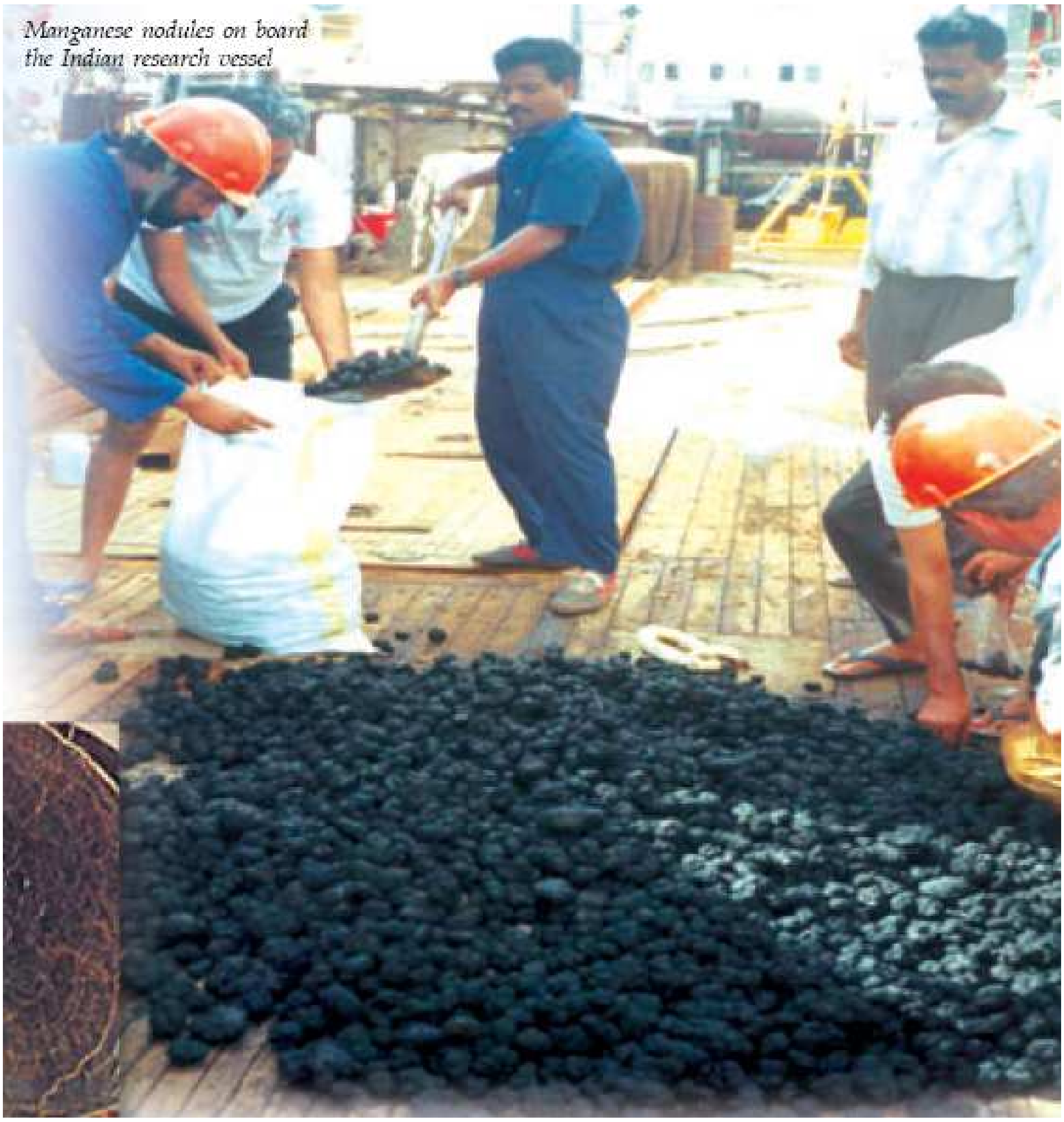


Photo.1.2. Mining Manganese nodules from Indian Ocean by Indian scientists

Large deposits of natural gas were found in the Krishna- Godavari Basin (KG Basin)(Photo 1.3) during 1980s and are being extracted by ONGC. Now Reliance Industries also was given permission to exploit the natural gas. Large placer deposits of rare earth minerals (Photo 1.4) were also being extracted since long time by Indian rare earths limited in Ganjam district of southern Orissa, Kerala and some parts of Maharashtra. Beaches of Cennai and Visakhapatnam were developed as touristic resorts for the last few decades. Salt farming (Photo 1.5) is also very common in the estuarine and back water zones of east and west coasts of India. See the figures below.

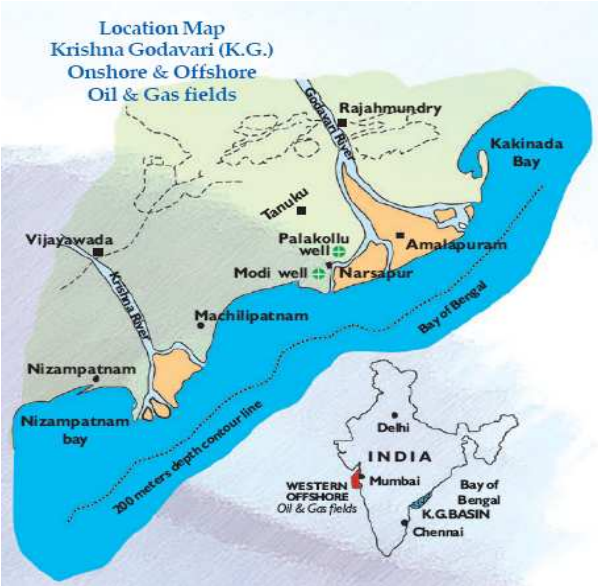


Photo1.3 Natural gas deposits of K.G.Basin

Photo1.4. Note the Black sands on the shore line at Visakhapatnam beach

Photo 1.5 Salt farming in west coast of India